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Vehicle Modeling & Data Analysis: Transportation Secure Data Center (TSDC), Fleet DNA and FASTSim

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National Renewable Energy Laboratory

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DOE Vehicle Technologies Office
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID #: eems049

Overview

Timeline

- Project start date: Jun 2017*
- Project end date: Oct 2018*
- Percent complete: 75%*

Budget

- Project funding
  - DOE share: $630K*

*Specific to first year support under the new EEMS program area. Effort builds on over a decade of work in the previous Vehicle Systems program area

Barriers

- Difficulty sourcing real-world data
- Difficulty accurately modeling large-scale systems and comprehensive scenarios
- Need for tools/techniques/insights at vehicle, traveler and system level, and sharing these

Partners

- U.S. DOT, State DOTs, Metropolitan Planning Organizations
- Fleets, Manufacturers, Suppliers
- NREL is the project lead

DOT = Department of Transportation

Relevance

- Relevant EEMS Program Strategic Goals*
  - Develop tools, techniques and core capabilities
  - Share research insights and capabilities with stakeholders
- Addressing EEMS Program Barriers*
  - *Difficulty sourcing real-world data on vehicles and travelers in the transportation system* – access to historic and present-day data is critical for real-world scenario evaluation and for model validation and calibration
  - *Difficulty accurately modeling large-scale systems and comprehensive scenarios* – an agile vehicle model that accurately captures the most important factors impacting energy consumption enables cost-effective exploration of wide-ranging scenarios and rapid, open-source/replicable application to large-scale real-world travel data (by anyone)
  - *Need for tools/techniques/insights at vehicle, traveler and system level, and sharing these* – the data and models are free of license costs and 3rd party software requirements, and are available through NREL's website (along with many publications by researchers who have used them)

*Anderson, David. "Energy Efficient Mobility Systems: EEMS Program Vision, Mission, Goals & Barriers." Slide presentation of Information for EEMS Program Annual Merit Review Presenters. January 30, 2018.

Objectives & Milestones

- Objectives
  - Work with partners to obtain and analyze real-world data for personal travel (in light-duty vehicles and other modes) and commercial vehicle travel behavior
  - Couple real-world travel insights with agile modeling to evaluate large-scale scenarios
    - Long-running NREL competency, additionally applicable to off-cycle credits analysis
  - Make research insights openly available, along with supporting data and tools
    - Enable independent replication and extension of research by external stakeholders

Date	Milestone/Deliverable	Status
Quarterly	Quarterly progress updates	On-track/ongoing
March 2018	Report on enhancements to the Future Automotive System Technology Simulator (FASTSim) and data updates to the Transportation Secure Data Center (TSDC)	Complete
October 2018	Annual Report on Vehicle Technology Evaluations and Fleet DNA	On-track

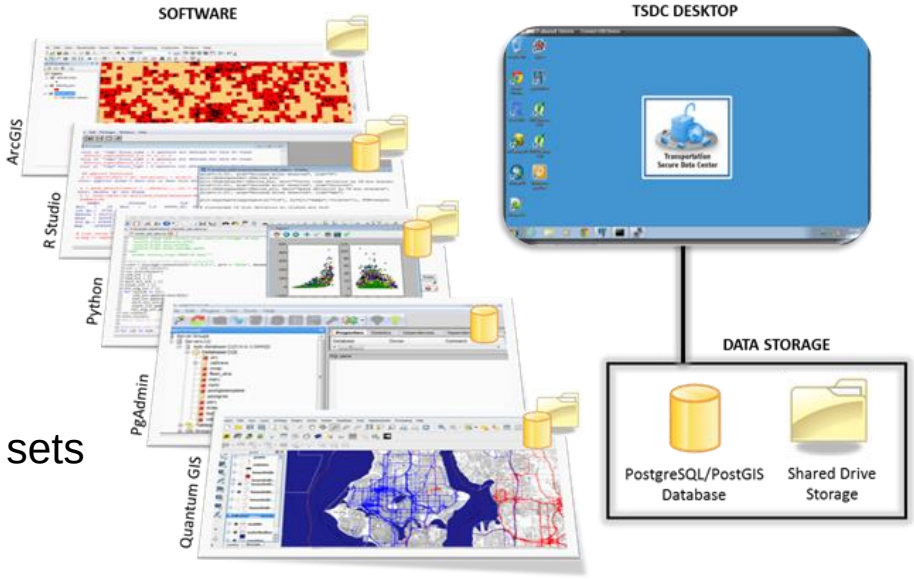
Approach: Transportation Secure Data Center

TSDC was established in 2009 due to increasing collection of high-resolution travel data (e.g., GPS trajectories, geo-coded trip ends) in surveys/studies

- Jointly supported by DOT FHWA and DOE VTO
- Data are very valuable for energy and travel research, but misuse could violate individual privacy

Secure data center makes data available for legitimate research while preserving privacy of participants

- Maximizes value from limited public funds
- Benefits data providers and users
  - Alleviates burden of archiving data and responding to data requests
  - Data accessible from a central location



TSDC operating procedures include

- Public website for downloading cleansed data sets
- Secure portal for approved users to work with detailed spatial data
- Advisory committee to support oversight, setting procedures, and reviewing data access applications

GPS: global positioning system
FHWA: Federal Highway Administration
VTO: Vehicle Technologies Office

Approach: Fleet DNA

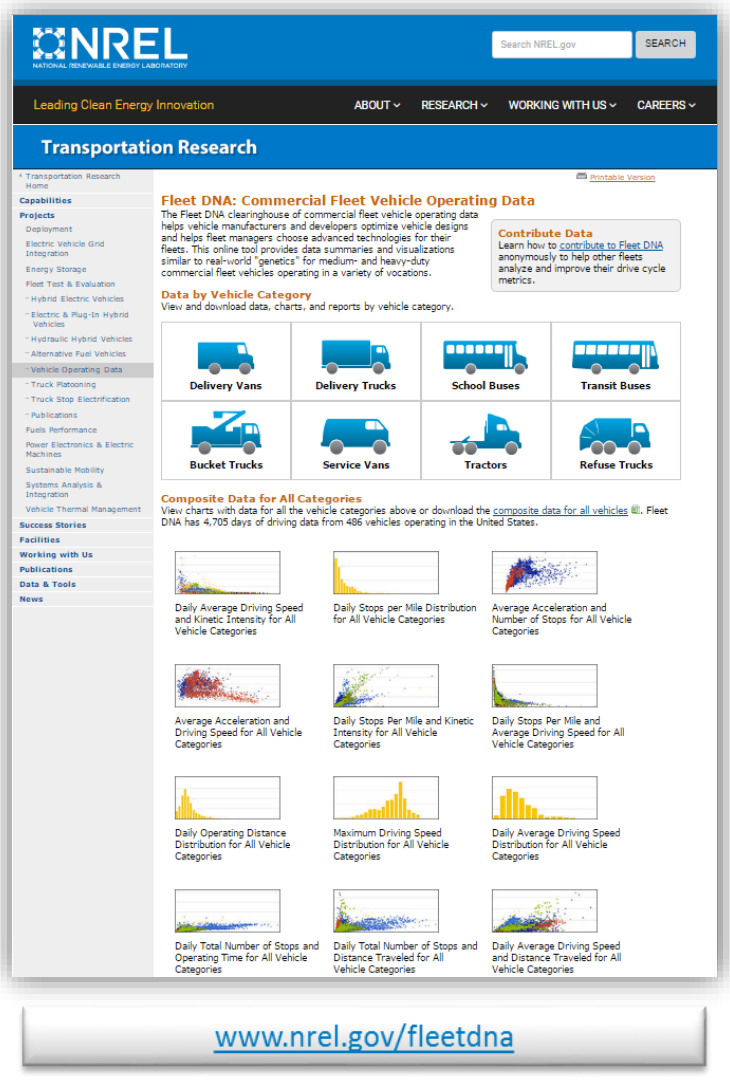
Fleet DNA was established in 2012 to:

- Capture and quantify drive cycle and technology variations for the multitude of medium- and heavy-duty vocations
- Provide a common data storage warehouse for medium- and heavy-duty vehicle fleet data across DOE activities and labs
- Integrate existing DOE tools, models, and analyses to provide data-driven decision making capabilities

Fleet DNA operating procedures include:

- Public website for downloading aggregated duty cycle statistics by vehicle vocation and weight class
- Secure database for storage and protection of raw data
- Fusion of data with other data sets – chassis dynamometer, road network, road grade, weather, vehicle specifications, vehicle registration data
- Integration with analysis tools – FASTSim, DRIVE
- Advanced analytics and High Performance Computing
- Applications and new data sources in partnership with industry, government and research partners

DRIVE: Drive-Cycle Rapid Investigation, Visualization, & Evaluation tool



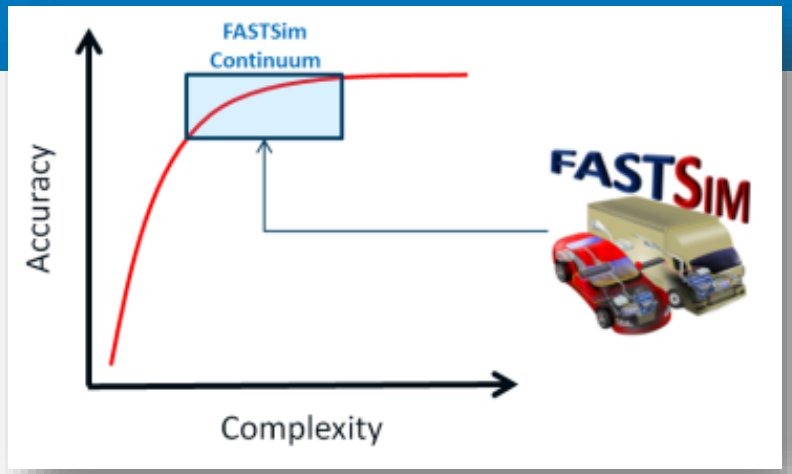
www.nrel.gov/fleetdna

Screen shot of Fleet DNA public website where anonymized, aggregated duty cycle statistics and data can be downloaded

Approach: Future Automotive Systems Technology Simulator

FASTSim balances accuracy vs. complexity

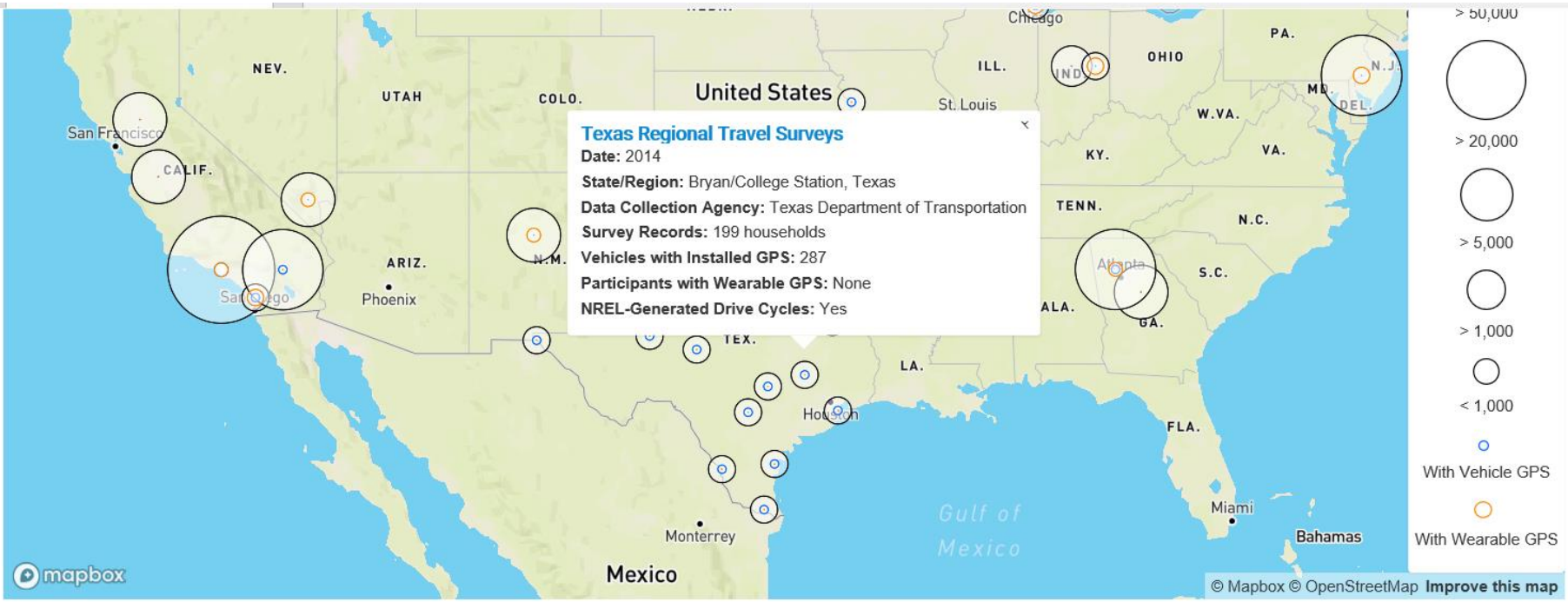
- Model captures most important factors influencing vehicle fuel economy, performance, and cost (including powertrain technology, vehicle and component sizes, how the vehicle is driven, etc.)



FASTSim itself occupies a continuum, varying the accuracy vs. complexity tradeoffs

Level of Modeling	Strengths	Limitations
Standard Option		
• Default power vs. efficiency maps for each component • Maps scaled based on component power ratings for modeled vehicle	• Fastest to calibrate: requires small amount of public vehicle information • Suitable for large-scale simulation/ evaluation of thousands of vehicle designs	• Captures most important factors for high-level comparisons but lacks detail for focused studies on a specific vehicle
Customized Option		
• Vehicle-specific component calibration	• Provides more precise model of specific vehicle(s)	• Larger calibration burden: requires detailed component-level data from manufacturer or testing
Potential Extensions for Targeted Investigations		
• Temperature dependence • Torque vs. speed disaggregation • Shift schedules	• Even more detail for studies that need it • Precise validation in numerous dimensions and conditions	• Further raises calibration burden • Still not suitable for applications requiring real-time control (e.g., hardware-in-the-loop testing)

Accomplishments: TSDC Data Sets



Cleansed Data by All Criteria

To browse data from transportation studies and surveys by name, agency, date, and other criteria, use our searchable and sortable data table.

Study/Survey Name	Year	State(s)/Region	Data Collection Agency	Survey Records	Vehicles with Installed GPS	Participants with Wearable GPS	NREL-Generated Drive Cycles
Atlanta and Seattle Tolling Impact Survey	2011	Georgia and Washington (Atlanta and Seattle)	U.S. Department of Transportation	10,561 participants	–	–	–
Atlanta Regional Travel Survey	2011	Georgia (Atlanta Region)	Atlanta Regional Commission	25,797 participants	797	1,653	✔
California Household Travel Survey	2010-2012	California	California Department of Transportation	109,113 participants	2,910	7,574	✔
California Household Travel Survey Supplement	2012	California	Southern California Association of Governments	473 households	625	244	✔

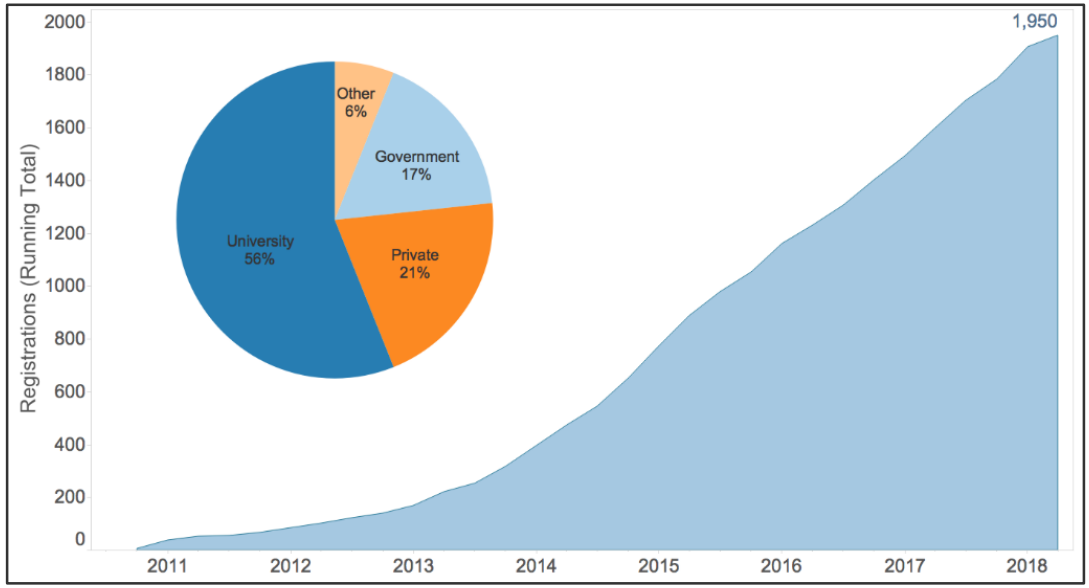
Spatial Data

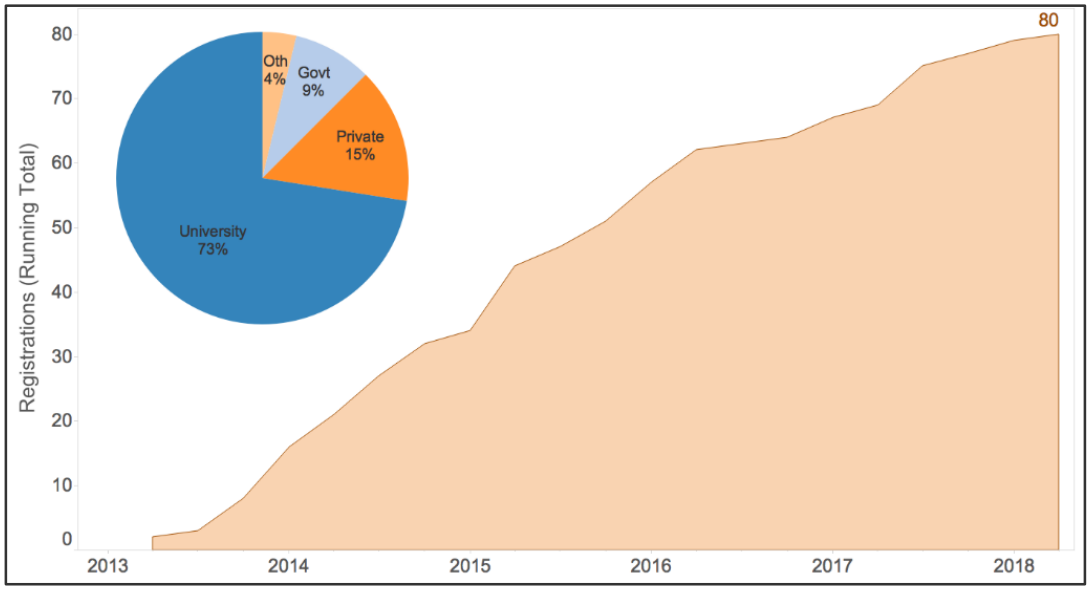
To access latitude and longitude spatial data from transportation studies and surveys, you'll need to submit an application.

LEARN HOW

Accomplishments: TSDC Resource Availability and Enabled Research Results

- The TSDC continues to see substantial growth in the number of external users accessing the resource
- Access to the data enabled publication of ≈30 research papers in 2017 alone
- Relevant research applications include:
  - Real-world driving and parking profiles used to inform siting of charging infrastructure for potential future electrified vehicle market penetration scenarios
  - Analyzing prevalence of driving conditions detrimental for vehicle emissions control (in collaboration with industry partners)





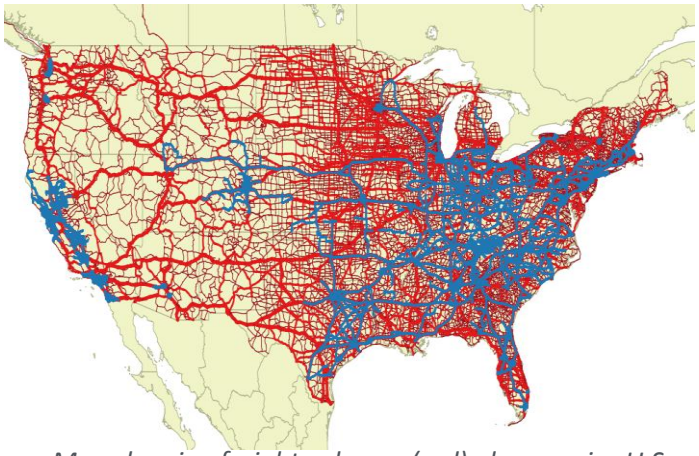
Accomplishments: Fleet DNA Data and Analysis

Scientific Approach & Accomplishment

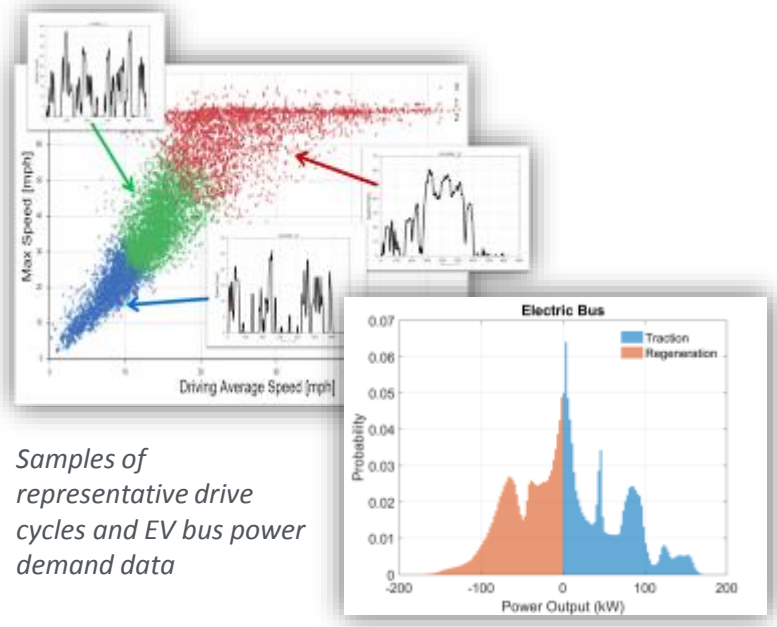
- Fleet DNA features 11.5 million miles of 1-Hz engine controller area network, GPS, and component data from 1,700 vocational vehicles operated by fleet partners—***UPS, FedEx, Coke, Frito-Lay, Foothill Transit, PG&E, Verizon, Walmart, Waste Management, Port of Long Beach, and more***.
- NREL has applied multi-variate data analysis, data fusion, and visualization techniques—such as principal component analysis and hierarchical clustering—to assist industry partners in optimizing advanced powertrains.

Significance & Impact

- Fleet DNA helps users understand the broad operational range of commercial vehicles across vocations, technologies, and weight classes.
- The data-driven insight and decision-making capabilities facilitated by Fleet DNA support a variety of DOE research activities and industry partnerships.
- Recent industry partners: ***Cummins, PACCAR, Peterbilt, Ford, GM, Proterra, Navistar, Eaton, Allison, Bosch, Odyne, Smith EV, BAE Systems, Efficient Drivetrains, Blossman, TransPower.***



Map showing freight volumes (red) along major U.S. roadways and Fleet DNA data coverage (blue) along those routes.



Samples of representative drive cycles and EV bus power demand data

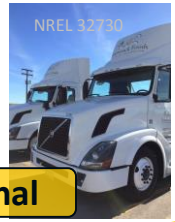
Accomplishments: Widespread Application of Data & Analysis

Fleet Partners

UPS
Frito-Lay
FedEx
Coke
Aramark
Shamrock

** Baseline conventional data also included*

DOE Vehicle Technology Evaluations*



Expanded Uses

Actively Supporting Current DOE Industry FOA Awards

- **Eaton** Multi-Speed EV Gearbox
- **Bosch** Medium-Duty Urban Range Extended Connected Powertrain
- **Cummins** - Electric Truck with Range Extending Engine
- **Blue Bird EV School Bus**
- **Super Truck II**
- **ARPAe NEXTCAR**
- **Zero Emissions Cargo Transport**
- **Blossman Gas** Propane DI Engine

Federal Agencies
- U.S. EPA
- National Park Service
- U.S. DoD
- USAID

Representative Test Cycles & Modeling

DOE VTO/FCTO Program Support
- EEMS Multi-Modal, CAVs
- Electrification
- Fuel Cell Trucks
- Technology Integration
- Fuels & Combustion

State Agencies
- California Air Resources Board (CARB)
- California Energy Commission
- South Coast Air Quality Management District

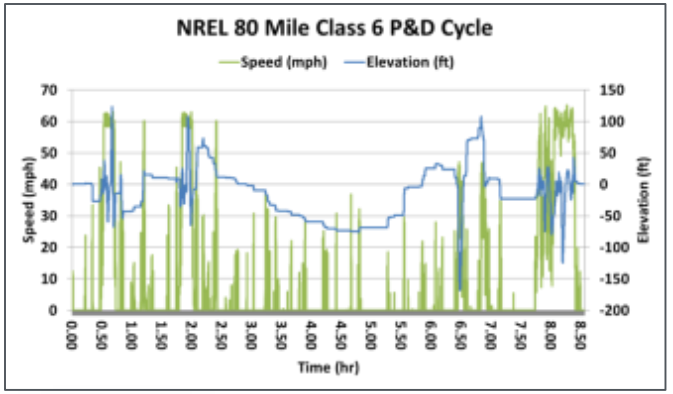
Sample Application – Medium-Duty Range-Extended EVs

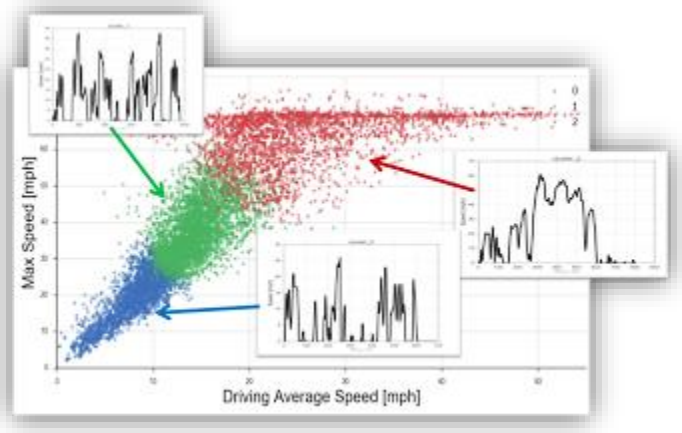
Scientific Approach & Accomplishment

- Leveraging Fleet DNA data to characterize real-world duty cycles from urban delivery vehicles, NREL applied the k-medoid clustering algorithm to segment in-use driving profiles into operational modes and developed representative drive cycles for various modes using the DRIVE tool.
- NREL developed analytical methods to incorporate other parameters, such as road grade and idle time, into the drive cycles.
- NREL's drive cycles are being used to size drivetrain components to meet performance requirements and validate performance relative to program objectives.

Significance & Impact

- This work was conducted as part of two industry partnerships under DOE FOAs led by ***Cummins*** *and* ***Robert Bosch*** to develop commercially viable, range-extended EVs for urban delivery applications targeting a 50% efficiency improvement.
- NREL's reusable methodology has been applied in a range of vehicle vocations, including Class 8 drayage trucks at the Port of Long Beach; a related SAE journal article was published in 2016.





NREL-developed representative drive cycles are used by ***Cummins*** *and* ***Bosch*** *in powertrain optimization and performance evaluations.*

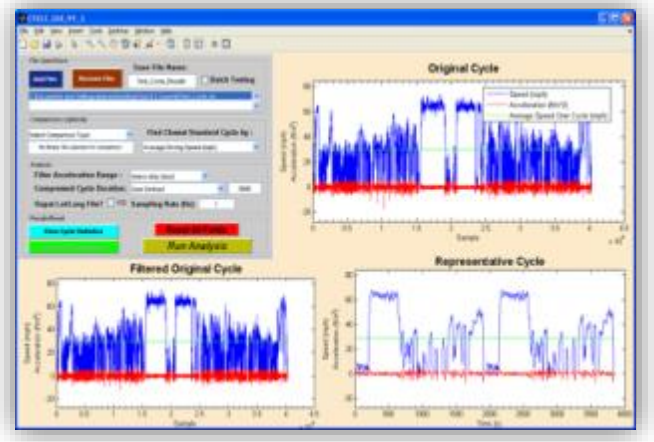
Accomplishments: Real-World Drive Cycle Development and Applications

Scientific Approach & Accomplishment

- NREL's DRIVE tool uses GPS and controller area network data to characterize vehicle operation and produce statistically representative drive cycles based on real-world activity.
- DRIVE analyses cover 168 unique drive-cycle metrics to generate custom representative drive cycles from "ideal" sections of filtered data using specialized statistical clustering methods.
- The Drive-Cycle Analysis Tool (DriveCAT) provides an inventory of downloadable vocational drive cycles for use by industry and researchers.

Significance & Impact

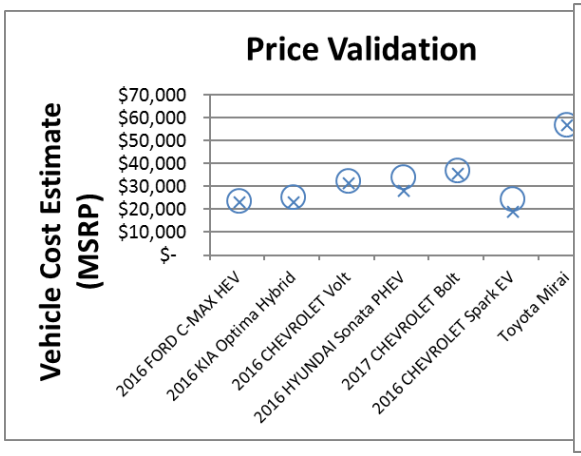
- Representative drive cycles are used by industry, government, and research partners for powertrain development and design optimization.
- Recent industry and research applications include: ***Eaton, Bosch, Cummins, Peterbilt, Allison, Blue Bird, ORNL, EPA, ARB, SCAQMD, and TARDEC.***

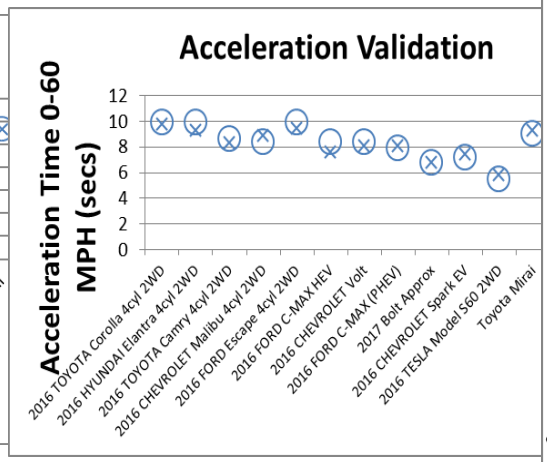


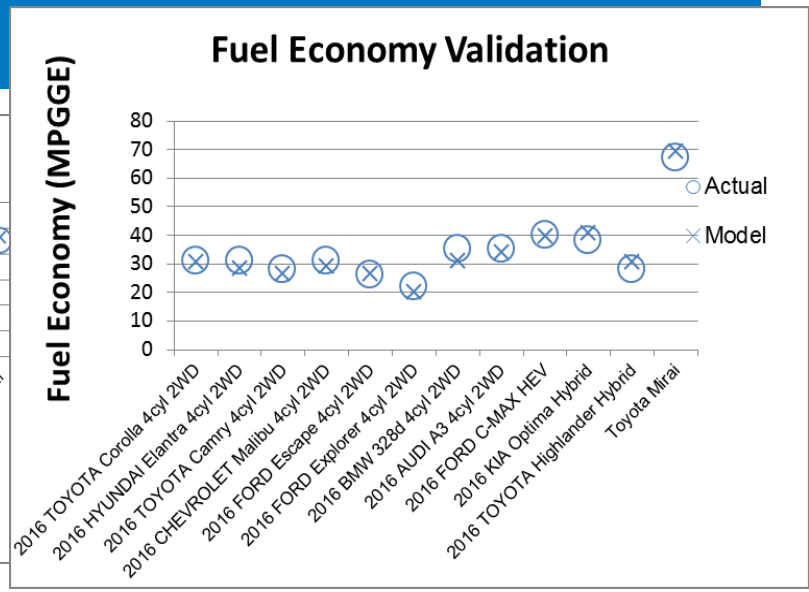
DRIVE's user interface displaying speed versus time plots of source data, cleansed data, and custom drive-cycle data.

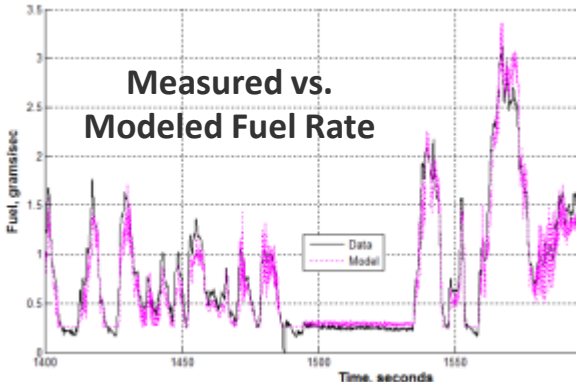
DriveCAT website where industry standard and NREL-developed drive cycles can be downloaded.

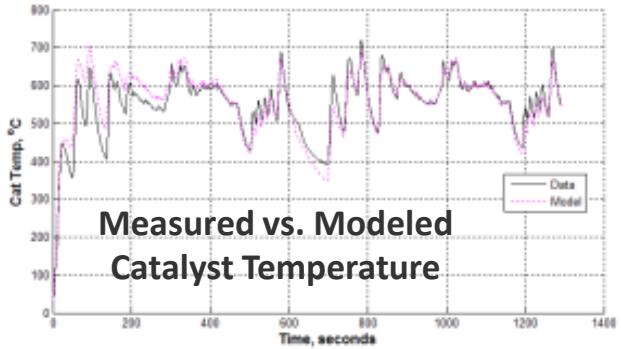
Accomplishments: Continual Validation for Standard and Extended FASTSim

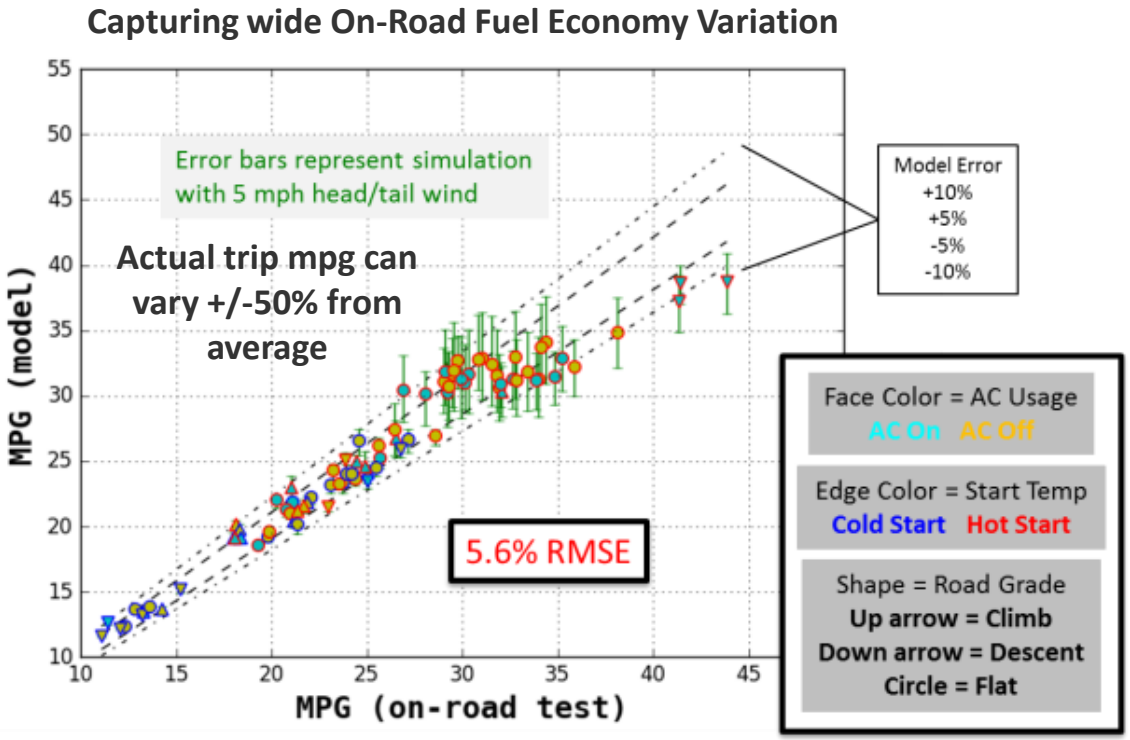












Accomplishments: FASTSim Resource Availability

- Website: Excel and Python versions available for download (free & open source)
- FASTSim Validation Report, and additional publications using the tool
- Interactive demo development and starter code
- Summary fact sheet

Automotive Deployment Options Projection Tool
Battery Lifetime Analysis & Simulation Tool
Battery Second-Use Cost Calculator
Commercial Fleet Vehicle Operating Data
Consumer Preference Data
Drive Cycle Analysis Tool
Drive-Cycle Rapid Investigation, Visualization, & Evaluation
Future Automotive Systems Technology Simulator
Transportation Secure Data

FASTSim: Future Automotive Systems Technology Simulator

The Future Automotive Systems Technology Simulator (FASTSim) provides a simple way to compare powertrains and estimate the impact of technology improvements on light-, medium-, and heavy-duty vehicle efficiency, performance, cost, and battery life.

This extremely fast simulation tool features a streamlined user interface and can rapidly perform a variety of tasks:

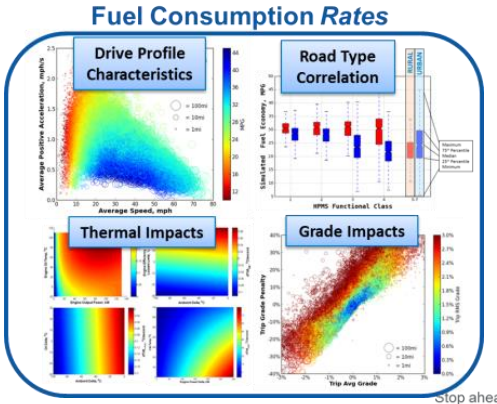
- < 0.1 second to simulate second-by-second standard duty cycles
- < 10 seconds to estimate vehicle efficiency, fuel economy, acceleration, battery life, and cost
- < 5 minutes to perform powertrain comparisons of efficiency and cost.

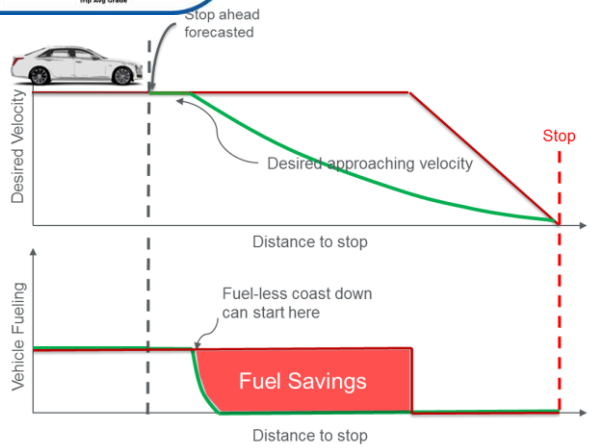
FASTSim models a wide variety of vehicle powertrains and fuel converter types:

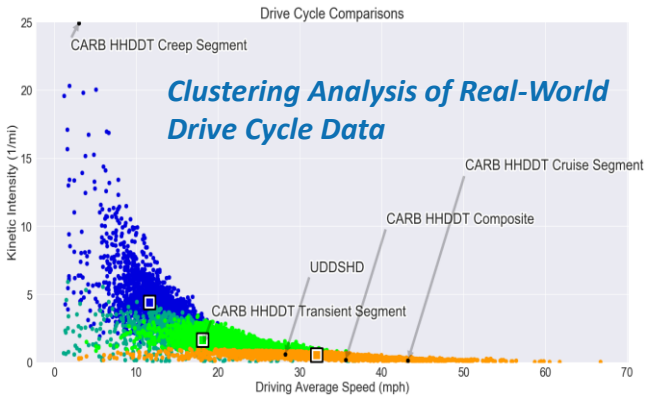
- Conventional vehicles — spark injection, Atkinson, diesel, and hybrid diesel
- Electric-drive vehicles — hybrid, plug-in hybrid, and all-electric
- Hydrogen fuel cell vehicles.

Accomplishments: Combined FASTSim and TSDC/Fleet DNA Research Application Examples

- Segregation and analysis of vehicle speed profiles in different driving conditions, and simulation for different vehicle/powertrain types
  - Used to train energy estimation modeling for green routing and aggregate “off-cycle” technology impact assessments, including for connected and automated vehicles
- Large-scale screening of prospective vehicle dynamics and powertrain control strategies prior to implementation by major automaker
- Opportunity assessment for commercial vehicle electrification
  - Worked with multiple industry partners to optimize HEV, EV and REEV powertrain requirements using FASTSim models simulated across a distribution of real-world vocational drive cycles and operational modes from Fleet DNA







Responses to Previous Year Reviewers' Comments

- **This project was not reviewed last year**.

Collaboration and Coordination with Other Institutions

- The organizations listed below, along with university/lab researchers and others, include partners for obtaining data and consumers of data, insights, and capabilities provided by the resources

Collaboration/coordination partners and activities include (further details in the back-up slides section):

- U.S. DOT, FHWA: Jointly support the TSDC with VTO
- Many MPOs and State DOTs: Contribute data from travel surveys and studies from their regions into the TSDC
- Other federal/state/local agencies: Leverage the resources
- Fleet Operators: Partner on vehicle instrumentation to collect use and performance data in specific applications; also consumers of data, insights and capabilities provided by the resources
- Manufacturers and Suppliers: Often support vehicle instrumentation; also consumers of data, insights, and capabilities provided by the resources
  - Implications of real-world demands on component design
  - Distribution of performance and efficiency at large scale
  - Estimating “off-cycle” technology benefits
  - Analyzing frequency of emissions-challenging driving conditions

DOT = Department of Transportation; FHWA = Federal Highway Administration; MPO = Metropolitan Planning Organization

Remaining Challenges & Barriers + Proposed Future Research Addressing Them

- New technologies & mode options will change travel behavior
  - Propose identification, collection and inclusion of new/on-going data in TSDC and Fleet DNA capturing these changes as they occur
- New sources of travel data becoming available
  - Propose starting to include large-scale probe data from various sources as complement to dedicated individual vehicle/traveler data collection
- Research effectiveness constrained by tool/feature updates
  - Propose pushing out updates to benefit all resource users, e.g.:
    - For TSDC and Fleet DNA – access to enhanced computational resources in addition to data
    - For FASTSim – updating with latest available vehicle models, and making new/in process feature enhancements broadly available (such as models of entire light-duty fleet, generalizing real-world thermal effects and impacts of latest technology enhancements on engines and other components)

Any proposed future work is subject to change based on funding levels.

Summary

- TSDC, Fleet DNA and FASTSim are valuable EEMS resources
  - Real-world data and analysis capabilities for assessing present-day and potential future vehicle/transport energy consumption and performance
- Accessible to lab and external researchers
  - Emphasis on maximizing data/information accessibility within constraints of protecting individual privacy and commercially sensitive data
  - Open source, and free of license costs and 3rd party software expenses
- Combination of resources enables agile, large-scale evaluations
  - Emphasis on validation and real-world data for credibility
  - Focus on most influential effects and fidelity needed for a given tasks → facilitates broad, cost-effective scenario evaluations
- Numerous application examples, including:
  - With DOE for advanced powertrain, connected/automated vehicle, and alternative fueling infrastructure evaluations
  - With industry partners for impact assessments of off-cycle technology and alternative powertrain design scenarios

Thank You

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Technical Back-Up Slides

Collaboration and Coordination with Other Institutions – Fleet DNA

Fleet DNA data and analysis tools were included in a wide range of collaborative activities in FY17/FY18, including:

DOE industry FOAs:

- Eaton Multi-Speed EV Gearbox
- Bosch Medium-Duty Urban Range Extended Connected Powertrain
- Cummins – Electric Truck with Range Extending Engine
- Blue Bird – EV School Bus Development
- Super Truck II – including applications on Cummins and PACCAR teams
- Purdue/Cummins/Peloton – ARPAe NEXTCAR connected powertrain control system for heavy-duty trucks, including advanced platooning
- South Coast Air Quality Management District – Zero Emissions Cargo Transport
- Blossman Gas and UPS – development of DI propane engine

DOE VTO and FCTO program support:

- Energy Efficient Mobility Systems – Multi-modal and CAVs pillars
- 21st Century Truck Partnership – presentation and feedback of Fleet DNA by 21CTP members
- Technology Integration – collaboration with National Park Service: evaluation of EV feasibility at Zion and Yosemite National Parks
- Fuel Cell Technologies Office – evaluation of duty cycles to evaluate fuel cells for commercial truck applications
- Lab collaborations – ANL, ORNL, LLBL, LLNL

Collaborations *funded by* other agencies include:

- U.S. EPA – analysis for phase II greenhouse gas rulemaking, MOVES model enhancements, on-road NO_x assessments
- CARB – vocational aerodynamics assessment, low-load NOx drive cycle development
- California Energy Commission – project with Proterra bus and Santa Clara Valley Transit to evaluate grid integration of high penetration EV transit buses
- USAID – evaluation of EV feasibility in Mexico City and Leon, MX
- South Coast Air Quality Management District – commercial zero- and near-zero emissions vehicle roadmap

Numerous add-hoc requests for data and analysis related to vocational vehicle duty cycles from industry and research organizations

Additional Collaboration and Coordination with Other Institutions – FASTSim & TSDC

FASTSim & TSDC data/analysis were included in further collaborative activities in FY17/FY18; examples include:

- Collaboration with app developer Metropia and multiple universities to deploy fuel-saving traveler feedback and incentives via ARPA-E's TRANSNET program
- Collaboration with GM to screen high-level powertrain and vehicle dynamics control alternatives over large-scale real-world driving profiles to prioritize options to further develop and implement in a test vehicle (ARPA-E NEXTCAR project)
- Collaboration with Toyota to analyze potential alternative powertrain designs over large-scale real-world travel profiles, and to enhance FASTSim's real-world modeling fidelity
- Collaboration with companies such as Bosch, Denso, Toyota and Hyundai to analyze
  - Distributions of real-world driving conditions relevant to emissions control and to performance of off-cycle fuel saving technologies
  - Simulation of off-cycle fuel saving technology implementations over large-scale real-world conditions to objectively estimate their aggregate benefit